Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

By JAMES A. MILLER

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1403–B

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1986

the subsurface, are at present unnamed in both Florida and Georgia. The permeable Cretaceous limestone that overlies the rocks of Taylor age is part of the Lawson Limestone of Navarro age.

CONFIGURATION OF SURFACE

Although the top of the lower confining unit represents a composite of the tops of several low-permeability horizons of different ages and different rock types, some of the large-scale features contoured on plate 33 reflect major structural elements in the eastern Gulf Coast. The east-trending low area centered near Brunswick, Ga., is part of the Southeast Georgia embayment; the negative area in Franklin and Gulf Counties, Fla., represents the Southwest Georgia or Apalachicola embayment; and the low area centered in Lee and Hendry Counties, Fla., is part of the South Florida basin. The steep, steady gulfward slope of the aquifer system's base in western panhandle Florida reflects the influence of the Gulf Coast geosyncline.

The axis of the positive area in northwestern peninsular Florida lies in an intermediate position between the axis of the Peninsular arch and the axis of the "Ocala uplift." This high area probably represents the approximate location of the Peninsular arch or is related to it, even though the axes of the two features do not exactly coincide.

In the broad area in peninsular Florida where anhydrite beds of the Cedar Keys Formation form the base of the aquifer system (pl. 33), the altitude of the highest anhydrite bed has been plotted and then contoured as if the evaporites were everywhere continuous. Actually, they are not. The anhydrite beds probably formed in tidal flat or sabkha environments that were of local extent (P. A. Thayer, personal commun., 1982) and, after burial, now occur as isolated discontinuous lenses that "float" in a mass of carbonate rocks. The lenses are confined, however, to a zone within the middle to lower third of the Cedar Keys, and it is the surface of this evaporite-rich zone that is contoured. Thus, the small, low- to moderate-relief (100 - 300 ft) positive and negative features shown on plate 33 in southern peninsular Florida, rather than being local structural features, represent local evaporite beds that occur at altitudes higher or lower than those of the main body of the Cedar Keys anhydrite-rich zone.

The faults shown in central Georgia on plate 33 are those that bound the series of small grabens called the Gulf Trough. The faults cut the low-permeability rocks that comprise the base of the aquifer system and displace them as shown. Because of the lack of deep well control in and adjacent to the Gulf Trough, the depth to which these faults penetrate is not known. Their geometry, however, indicates that they probably die out at a relatively shallow depth. The faults in southwestern Alabama, which also bound a series of grabens, also cut the base of the aquifer system. Unlike the faults that bound the Gulf Trough, the Alabama faults are known to extend to great depths (Copeland, 1968; Moore, 1971). To the south and west of the Alabama faults, the Floridan aquifer system is very thin and effectively isolated from the main body of limestone because movement along the faults has downdropped relatively impermeable beds opposite the permeable limestone of the aquifer system.

REGIONAL VARIATIONS IN PERMEABILITY

The rocks that make up the Floridan aquifer system are a series of platform carbonate beds that were laid down in warm, shallow water in an environment similar to that of the modern Bahama Banks. The original texture of the limestone ranged from micritic to biosparruditic (textural terms from Folk (1959)) and, like modern carbonates, varied considerably over short lateral distances, depending upon the exact depositional environment at a given place. Slight differences in the depth, temperature, and salinity of ocean waters or in current strength and distribution affect the types and numbers of calcium carbonate-fixing organisms that are present as well as the amount of micrite and the percentage and size of limestone pellets that can accumulate. As the carbonate sediment becomes consolidated, these organic and textural factors determine the primary texture of the limestone formed, which in turn determines the primary porosity and permeability of the rock. For example, the Ocala Limestone, which is part of the Upper Floridan aquifer, was deposited in shallow, warm, clear water and consists in many places of a coquina of bryozoan fragments and large Foraminifera loosely cemented with sparry calcite or a small amount of micrite. The permeability of the Ocala is high nearly everywhere. By contrast, gypsiferous dolomite of middle Eocene age (middle confining unit II) was deposited largely in a series of sabkhas or tidal flats, and has a very low permeability.

Diagenesis subsequent to deposition at any stage of consolidation of the rock can either enhance or decrease limestone permeability. For the Floridan aquifer system, dolomitization has been the chief diagenetic process affecting permeability. Depending upon the original limestone texture, dolomitization can increase or decrease the porosity of the rock. If the original rock is a micrite, it may be recrystallized into a loosely interlocking mosaic of dolomite crystals that is highly porous. On the other hand, if the originally high porosity of a loosely packed, coarsely pelletal limestone is almost completely filled with finely crystalline dolomite, an effective confining unit is created out of a once-permeable rock. The degree to which the original limestone porosity is affected depends also upon whether dolomitization is partial or complete; if the process is incomplete, some of the original porosity may be preserved. The exact mechanism by which dolomitization took place in the study area is unclear. Some of the observed dolomitization is possibly related to paleo or modern ground-water flow systems (Hanshaw and others, 1971; Hanshaw and Back, 1979). Periodic, perhaps repeated exposure of the limestones and flushing of their interstitial saline waters by freshwater is one mechanism by which the amount of magnesium-rich water required to dolomitize the limestone could be moved through the rock. This study, shows the the effect of dolomitization on limestone permeability is very important.

Rapid facies change can occur within a short lateral distance in the Floridan aquifer system, a result of closely spaced but highly variable depositional environments. Such changes may be textural within a limestone bed, such as an increase in the amount of micrite toward a relatively quiet water environment, or they may reflect, usually in an upbasin direction, the mixing of clastic materials with the limestone as one approaches an ancient shoreline. Complex interfingering and intertonguing of rock types and permeability conditions are thus produced, particularly in carbonate-clastic transition areas. The amount of fine-grained carbonate material in the Floridan aquifer system as a whole generally increases in a downbasin direction, so much so that, in parts of southern Florida, the aquifer system consists largely of low-permeability rocks separated by relatively thin, often vuggy, high-permeability zones that are hydraulically isolated from one another.

Geologic structure, like dolomitization, can either increase or decrease the permeability of a limestone. Because most limestones are relatively brittle, they tend to break rather than bend when they are subjected to stress. Joints are thus readily formed in carbonate rocks. In the Floridan aquifer system, borehole televiewer surveys and downhole current meter data show that, in places, joints cut some of the middle confining units and provide conduits along which water is able to move vertically from one permeable unit to another. Enlargement of joints can result from dissolution of limestone by ground water that moves along the joints. Data from wells in Brunswick, Ga. (well GA-GLY-9), and Broward County, Fla. (well FLA-BRO-2), show the effects of jointing on permeability. In contrast to the increase in permeability created by jointing, faults that cut all or part of the aquifer system may effectively decrease the permeability of the system in places and disrupt ground-water flow. The low-permeability materials downfaulted into the aquifer system in a series of grabens in western Alabama and central Georgia are examples of local decreases in permeability created by fault activity.

Most of the gypsum and anhydrite that fill the pore space in some of the confining units within the aquifer system apparently formed in a sabkha or other tidal flat environment. Petrographic examination of evaporite-rich limestone from a test well GA-WA-2 near Waycross, Ga.,however, shows that some of the evaporite minerals that fill the pore spaces in the limestone there were formed by secondary mineralization. Much of the anhydrite near Waycross appears to have been precipitated from ground water that was rich in calcium sulfate. Deposition of anhydrite or other types of pore-filling materials from circulating ground water has effectively decreased the porosity and permeability of the limestone near Waycross.

More commonly, circulating ground water increases the permeability of limestone by dissolution. Secondary porosity, developed as the carbonate rocks are partially dissolved, ranges in scale from pinpoint holes to isolated vugs to caverns tens of feet across. The larger solution conduits, of course, are the more important because they greatly increase the local transmissivity of the Floridan aquifer system. The karst features developed in the aquifer system are best known where the Floridan crops out or is thinly covered (pl. 25), but buried karst horizons, such as southern Florida's Boulder Zone, also occur and are of considerable importance. Stringfield (1966) discussed the near-surface karst features of the study area in detail.

It is obvious from the preceding discussion of the factors influencing the porosity and permeability of limestone that the distribution of permeability within the Floridan aquifer system is extremely complex, depending partly on the environment in which the limestone was deposited and partly on the postdepositional history of the rock. Certain generalizations can be made, however, about the relation between the geologic character of the aquifer system and its hydraulic properties. Figure 27 shows the estimated distribution of transmissivity in the Upper Floridan aquifer. Comparison of this figure with a map showing where the aquifer system is unconfined, thinly confined, and thickly confined (pl. 25) shows that all areas having transmissivity values greater than 1×10^6 ft^2/d, and many of the areas with values between 2.5×10^5 and 1.0×10^6 ft^2/d, occur where the aquifer system is either unconfined or where its upper confining unit is less than 100 ft thick. In these places, the upper part of the aquifer system is riddled with caves, sinkholes, pipes, and other types of solution features. The large-scale secondary porosity developed in and near the Floridan's outcrop area is the reason for the large

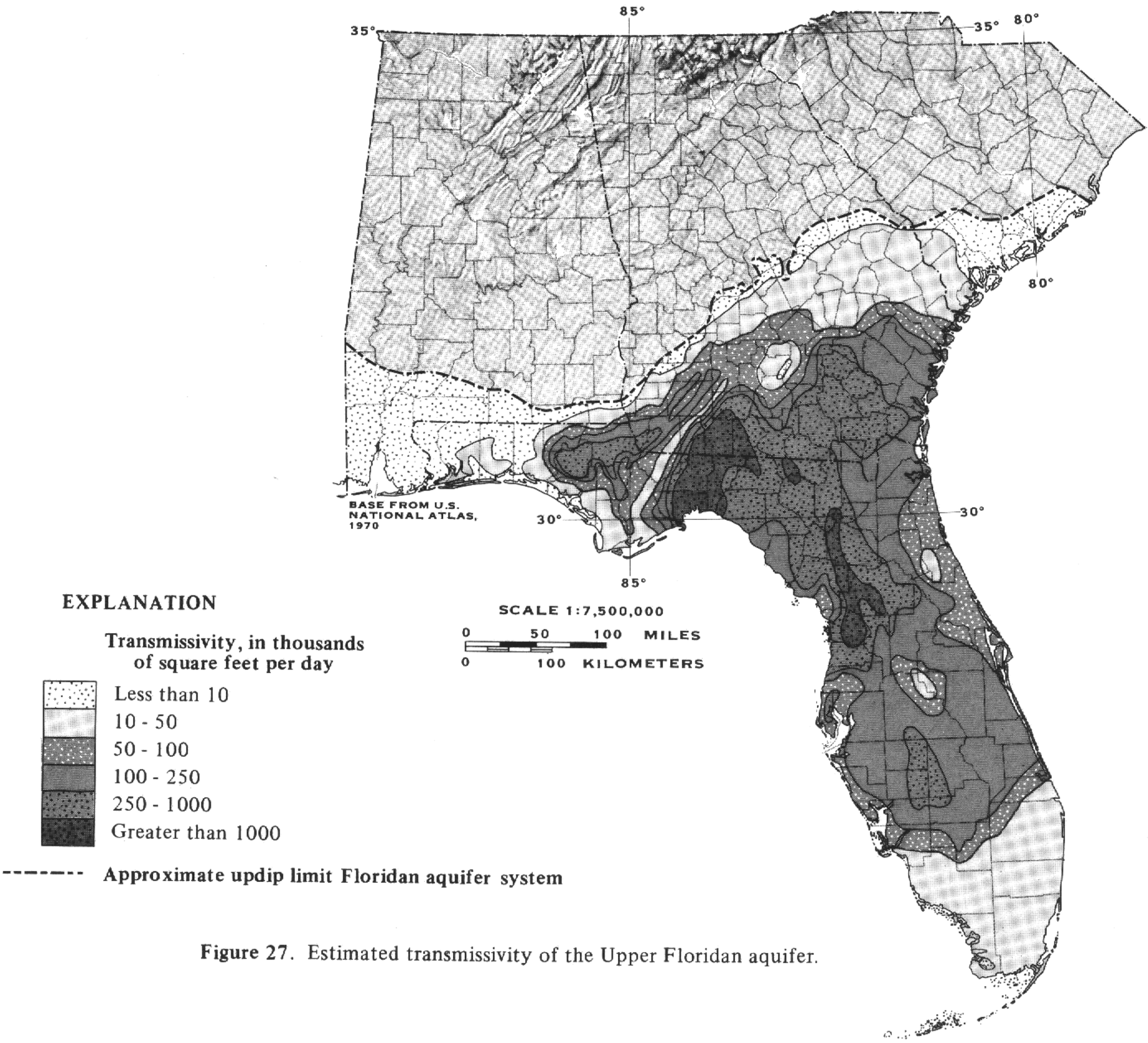

Figure 27. Estimated transmissivity of the Upper Floridan aquifer.

transmissivity values observed there. Where the aquifer system is thickly confined (pl. 25), its transmissivity is generally lower (less than 2.5×10^5 ft^2/d), and the variations that exist are related primarily to textural (facies) changes in the carbonate rocks and secondarily to the thickness of the Upper Floridan aquifer. For example, the mapped transmissivity values of less than 5×10^4ft^2/d in southern Florida result from a decrease in limestone permeability in an area where the aquifer system contains much micrite. Similar values near and just downdip of the aquifer system's updip limit (for example, in western panhandle Florida) are found in places where the Upper Floridan aquifer is thin (pl. 28). A band of low transmissivity extending northeastward across south-central Georgia is related to the small graben system called the Gulf Trough, discussed previously. Generally, then, the transmissivity of the aquifer system is most strongly influenced in and near its outcrop area by thickness and secondary permeability and, where the system is confined, by facies variations. A good example of this relation is shown by the upper Eocene rocks (Ocala Limestone) in figure 28. At Silver Springs, Fla., the Ocala is highly cavernous and forms the vents from which the springs issue (Faulkner, 1973). Downdip, these upper Eocene rocks become increasingly less permeable, chiefly because much of their pore space is filled either with micrite or finely recrystallized material, until, in Glades County, Fla. (well FLA-GL-1, fig. 28), upper Eocene rocks become part of the upper confining unit

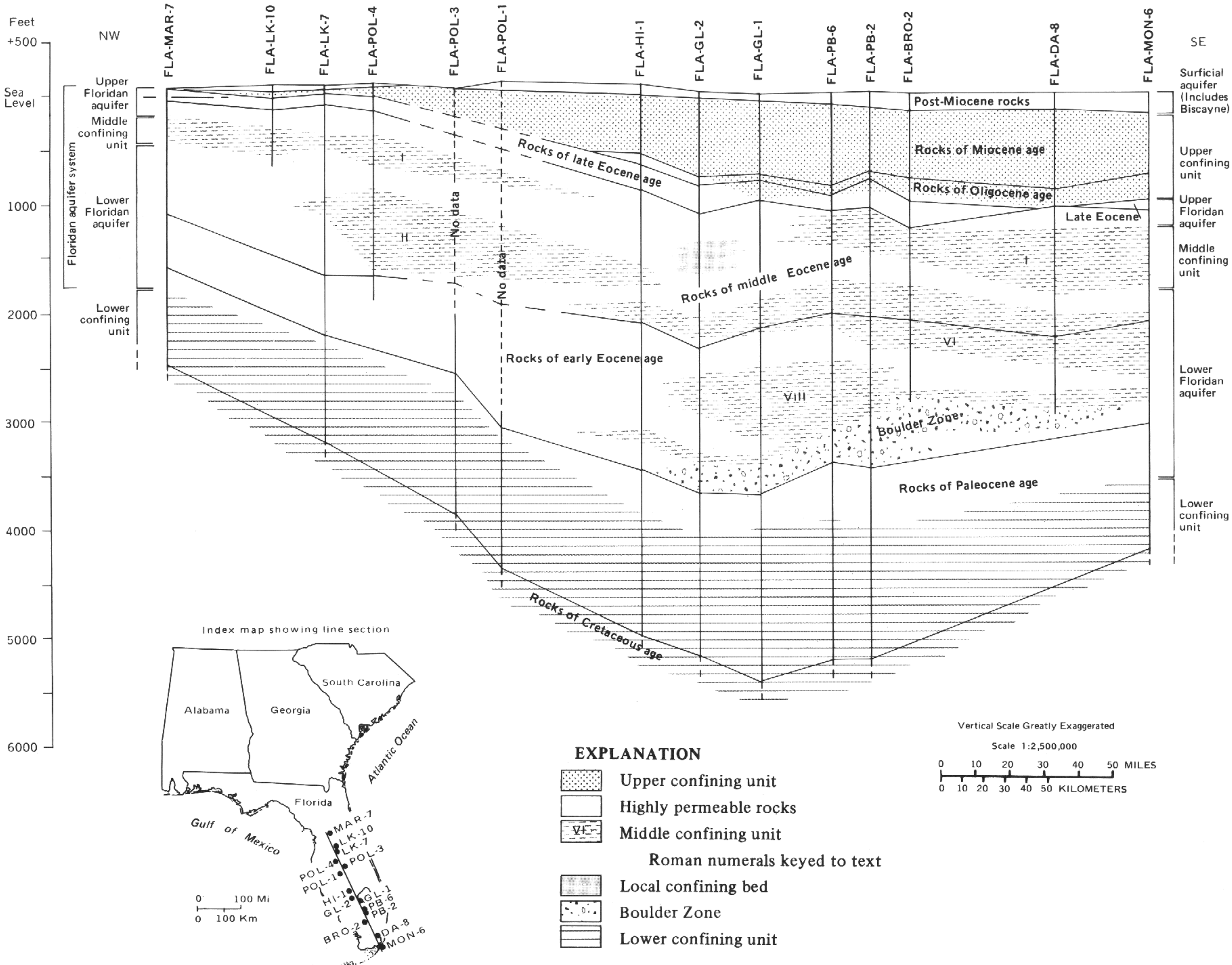

Figure 28. Generalized geohydrologic cross section from central Marion to northern Monroe Counties, Fla.

of the aquifer system. Farther south, as the amount of micrite in the Ocala decreases, upper Eocene rocks are again included as part of the aquifer system because their permeability is higher.

SUMMARY AND CONCLUSIONS

The Floridan aquifer system of the Southeastern United States is comprised of a thick sequence of carbonate rocks that are mostly of Paleocene to early Miocene age and that are hydraulically connected in varying degrees. Locally, the aquifer system includes rocks of Late Cretaceous age. In and near its outcrop area, the system consists of a single vertically continuous permeable unit. Downdip, there are generally two major permeable zones (the Upper and Lower Floridan aquifers) separated by a middle confining unit of subregional extent, whose hydraulic properties vary from very leaky to virtually nonleaky. Neither the vertical boundaries of the aquifer system nor its component major high- and low-permeability zones necessarily conform to either formation boundaries or time-stratigraphic breaks. Commonly, the permeability contrast that distinguishes the Floridan aquifer system from its upper and lower confining units occurs somewhere within a rock or time-rock unit.

The subsurface stratigraphy of the coastal plain rocks that comprise the Floridan aquifer system and its contiguous confining units was delineated and mapped on the basis of data from deep test wells of various types. Chronostratigraphic units were chosen for mapping because such units best portray conditions throughout an entire sedimentary basin when complex facies changes such as those found in the eastern Gulf Coast are present. Each chronostratigraphic unit that was delineated includes all or parts of several surface and subsurface formations. The external geometry of each chronostratigraphic unit is shown by structure contour and isopach maps, and internal variations in the units are shown on a series of cross sections that also portray major variations in permeability.

Coastal plain sediments in the eastern Gulf Coast are predominantly clastic from the Fall Line that marks their inland limit. These clastic rocks merge into and interfinger with a thick sequence of platform carbonate rocks that underlies all of peninsular Florida and much of southeastern Georgia. From Paleocene through Oligocene time, the platform carbonate facies successively encroached on the clastic rocks, the result being that progressively younger Tertiary carbonates extend progressively farther to the north and west. The general gentle seaward thickening of coastal plain rocks is interrupted by large- to small-scale geologic structures. Some of these structures, such as Florida's Peninsular arch, the Southeast and Southwest Georgia embayments, and the South Florida basin, have had a major influence on sedimentation and permeability distribution. The Gulf Trough fault system in central Georgia and the Gilbertown-Pickens-Pollard fault zone in southwestern Alabama both strongly influence ground-water flow within the Floridan aquifer system.

Rocks of Cretaceous age underlie the entire study area and generally consist of low-permeability calcareous clay and fine-textured limestone. Updip, sandy Cretaceous rocks form part of the lower confining unit of the Floridan aquifer system except very locally, in the Brunswick, Ga., area, where the upper Cretaceous Lawson Limestone is part of the system.

Paleocene rocks are generally of low permeability throughout the study area except for the permeable dolomite beds in the upper part of the Paleocene Cedar Keys Formation in peninsular Florida, which are included in the Floridan aquifer system. Thick extensive deposits of Paleocene anhydrite in the Florida peninsula form the base of the aquifer system there. Glauconitic Paleocene clastic rocks to the northwest are part of the aquifer system's lower confining unit. The Paleocene-early Eocene boundary is placed in this report at the highest occurrence of either of the planktic Foraminfera *Globorotalia pseudomenardii* Bolli or *G. Velascoensis* (Cushman).

Lower Eocene rocks in the Florida peninsula are part of the Oldsmar Formation, a sequence of limestone and dolomite beds that is in general highly permeable. Like the Paleocene rocks that underlie them, lower Eocene carbonate rocks grade to the north and west into calcareous, glauconitic clastic rocks that are of low permeability. Middle Eocene carbonate rocks in the Florida peninsula have traditionally been divided into the Lake City Limestone below and the Avon Park Limestone above. Well cuttings and core examined during this study show no consistent lithologic or paleontologic difference between the Lake City and Avon Park Limestones. Accordingly, this report proposes that the term Lake City be abandoned and that all middle Eocene carbonate strata in the Florida peninsula and contiguous areas be included in the Avon Park Formation. A reference well section is suggested for the expanded Avon Park Formation. This report further proposes that the term "formation" rather than "limestone" be applied to the Avon Park, Oldsmar, and Cedar Keys units because all commonly contain rock types other than limestone. Middle Eocene rocks show the same westward carbonate-to-clastic transition as lower Eocene and Paleocene strata. This transition occurs farther northward and westward than that of the lower Eocene, which is in turn north and west of the Paleocene clastic-carbonate transition. Most of the low-permea-